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INTRODUCTION

Now that aerospace technology has come full circle from aircraft that flew long before any thought of space flight, through space vehicles that could never be mistaken for aircraft, and now back to space vehicles that must also fly as conventional aircraft, it is appropriate to look at a rarely considered, but potentially disastrous, phase of aircraft operations: the overrun accident. That simple fact is that so long as aircraft continue to land on runways, occasionally one will fail to stop within the available distance. Without proper protection, this event can range in import from a red-faced pilot, through fractured landing gear and wrinkled skin, to total destruction.

The discussion which follows will review briefly the history and development of arrested landing, introduce existing equipment capable of arresting either component of the space shuttle, and present some thoughts on how best to adapt these space vehicles to overrun protection by emergency arrestment.

BACKGROUND

To most people, arresting gears and arrested landings immediately connote an aircraft carrier, and a pilot strapped in for all he's worth to resist the high loads of what some people have labeled a "frightful arrival." This is only a part of the story. Let us review briefly the last 60 years of aircraft arrestments.

In 1911 a young Navy lieutenant named Ely landed his crude biplane aboard the USS Langley. On touchdown, a hook trailing below the aircraft engaged a cable stretched across the deck, attached at each end to some bags of sand. The energy of the aircraft was transferred into the sandbags until the whole combination came to rest. The world's first arrested landing had become history.

By World War II, arrested carrier landings were routine and every carrier based aircraft had a tailhook as its primary engaging device. But a second means of engagement had been introduced. A steel barricade net was erected ahead of the landing zone but behind the aircraft parked on the forward portion of the deck.

Its purpose was not to save a landing aircraft which failed to engage with its hook, but to protect the aircraft parked forward. Thus were introduced the two primary means of making connection between an aircraft and an energy absorber designed to arrest its forward motion. There are other engaging means which we will discuss later in passing; we will also look at some energy absorbers, past and present.

In the post World War II period the British introduced the canted deck carrier in which the landing path lay at an angle to the ship's axis. This meant that the barricade could be abandoned because there were no parked aircraft in front on the landing zone, but further, in the event of a missed engagement, the pilot could take right off and go around for another try. This configuration and procedure is used today at a rate of more than a quarter of a million times a year with a reliability record that is near perfect. Present carrier arresting equipment handles aircraft weighing up to approximately 50,000 pounds with landing speeds relative to the deck of about 125 knots.

Air Force overrun experience on runways in Korea with the early jet fighters led to the improvisation of an arresting barrier made up of an anchor chain on either side of the runway connected to a device which would engage the landing gear. This system is known at the MA-1A barrier and is still widely used today. The barrier is connected to the chain in such a way that the chain is put into motion only one link at a time, not all at once. The Navy also used the anchor chain but with a cross runway cable for hook engagement.

From this point on, development of runway arresting systems progressed rapidly. The Air Force put hooks on all its Century Series fighters and have continued to do so on all new designs. The standard hook installation on three aircraft in the Century Series, the F-100, F-101 and F-106, is a Sheaffer Spring Arresting Hook. This hook was specifically developed by All American Engineering Company for emergency arrestments and offers maximum protection at a minimum cost and weight penalty. Many of the countries in the world adopted engagement systems useing nets of steel or nylon which would envelop an aircraft's wings. Energy absorbers were developed using rotary friction, linear friction, inear hydraulic, and rotary hydraulic means of energy absorption. Overrun arrestment has become an accepted and welcome technique with most of the Free World's military air arms.

Application of arrestment techniques to civil aviation was also explored. Under an FAA contract in 1960, All American Engineering Company built and tested a linear hydraulic arresting gear capable of arresting a civil transport weighing 350,000 pounds from 130 knots in 1,750 feet. A hook-equipped Boeing 720 was arrested in manned tests.

Modification of the world's civil transport fleet for tailhooks was considered to be impractical so alternate engaging means were explored. Following earlier development work in France of an all nylon net big enough to completely envelop the wings of a 4-engine jet transport, a full size system was recently demonstrated with support from the French Air Ministry, the French net manufacturer Aerazur Constructions Aeronautique, the FAA, and USAF. Tests were run last November and December in which a B-52 bomber weighing 305,000 pounds was arrested from 115 knots in 1,200 feet by an All American Model 64 rotary hydraulic "Water Twister"[R] and the Aerazur net.

Figure 1 shows the aircraft just prior to wing engagement of the net.

THE MODEL 64 ENERGY ABSORBER SYSTEM

The Model 64 is the largest of a family of rotary hydraulic energy absorbers whose configuration is shown in Figure 2 and whose principle of operation is described below.

The Water Twister is an energy absorbing water brake that converts kinetic energy to heat through fluid turbulence. Physically, the energy absorber consists of a fluid filled steel casing which houses a vaned centrifugal rotor and opposing stator vanes.

The rotor is mounted on a shaft which extends out of the top of the casing. A storage reel for a nylon tape or purchase element is attached to the top end of the rotor shaft. Nylon tape is wound onto this storage reel forming a spiral wrap. A Water Twister is installed on either side of the runway and the two nylon tapes are then joined by a nylon net stretched across the runway. For aircraft equipped with tailhooks, the nylon net is replaced by a wire pendant.

R Registered Trade Mark

In operation an aircraft engages the net or pendant and unwinds the tapes off the storage reels. Pulling the tape off the reels causes them to rotate, turning the shafts and the energy absorber rotors. The rotors, immersed in fluid, create turbulence and viscous shear which convert the kinetic energy to heat. The torque of the rotors apply the retarding force which stops the aircraft.

As the tape unwinds from a reel, the diameter of the outer layer of tape on the reel decreases. If the tape were payed out at a constant rate, the reel would increase its rotational velocity. Because the airplane is slowing during runout, the velocity of tape payout is decreasing which, in turn, reduces the rotational velocity of the reel. In practice, these two factors are designed to balance one another so that the rotational velocity and the torque of a Water Twister tends to remain constant during aircraft runout. The torque then applies a relatively constant deceleration force to the aircraft.

The Water Twister is an uncomplicated device and seldom requires maintenance. There are no mechanical or electrical controls required. If left in the 'ready' position, it is always ready to stop any airplane within its designed performance envelope. Individual adjustments are not required to arrest aircraft within the design weight and speed envelope. It may be left unattended for long periods without degrading its reliability, so that a round-the-clock emergency arresting system can be maintained without requiring an operator in attendance.

Figure 3 depicts a typical general arrangement of a Water Twister arresting gear installed on a runway. A gasoline rewind system is shown but this can be varied or omitted to suit specific requirements.

The energy absorber is a theoretically constant runout device which automatically adjusts the retarding force to suit the weight and speed. Figure 4 shows typical curves of retarding force vs. runout distance for optimum (design) weight, light weight, and heavy weight aircraft engaging at the same speed. In general, the weight determines the shape of this curve; its amplitude will vary approximately with the square of the engaging speed.

Figure 5 is a composite performance chart for the Model 64 showing capability for weights up to 400,000 pounds and speeds up to 160 knots. Consideration of these values shows that the Model 64 as it now exists can arrest the Orbiter from any reasonably anticipated overrun speed.

In selecting the capacity of the Model 64, full recognition was taken of the supersonics and the jumbos. There exists a limit to the weight range which can be reasonably handled with a given energy absorber. With low G tolerance vehicles, weight ratios of 4:1 maximum to minimum can be accommodated comfortably. Beyond this, the sheer mass of the system required to arrest the maximum weight/speed vehicle will cause excessive loads on the lightweight vehicle during engagement and initial system acceleration. For this reason, a single Model 64 is intended for use with aircraft of 707, DC-8 size or smaller. For the outsize aircraft such as the 747 or SST, a tandem system is used. Performance of this combination can be read from Figure 5 by doubling the aircraft weight scale and the values of the constant retarding force lines. The lines defining "G" do not change. This tandem approach was further supported by the economic advantage of having a fully defined system (the single one) available for those airports which would not be faced with outsize aircraft operations. Only those fields anticipating the jumbos or supersonics need install the tandem system. Selective erection of one or two nets would be made to suit the aircraft requiring arrestment. Until a barrier engagement is required, all nets are below runway surface; erection requires less than two seconds.

The same dual Model 64 has ample capacity to arrest the Space Shuttle Booster at any projected weight up to 800,000 pounds.

SPACE SHUTTLE ADAPTATION

In the discussions above, three engagement methods have been disclosed:

1. Tailhook/cable
2. Net
3. Landing gear/cable

Any of these could be adapted to the Space Shuttle but each has its advantages and disadvantages.

The tailhook is the neatest method since it applies all loads through a definable load path. There are no loads applied to lightweight skins, fairings, or aerodynamic control surfaces and it permits instant disengagement. Within the military services to whom arrestment is becoming a way of life, this method continues to grow in popularity. It is important to note that a military organization is an entity into itself and therefore can dictate a full system and its mode of operation.

As mentioned earlier, the task of persuading all the world's airlines to agree on installation of hooks on all their transport aircraft, plus obtaining the approval for such a system from all the national and international agencies involved in civil air transport appears insurmountable. As a result, all present efforts toward civil transport arrestment are based on use of a net which will engage any aircraft which enters it and requires no modification of anyone's aircraft. The net does offer the advantage of universality although there does exist a potential of minor damage to wing leading edges, slats, fairings, and the like from local strap loads. This type of damage would be minimal because of the excellent distribution of loads from the many individual straps. This certainly is inexpensive when compared to a destructive overrun.

The third method, landing gear engagement, in spite of its still widespread use, is gradually being discarded. The dynamics involved in elevating a cable in front of the main gear after passage of a nosewheel make it extremely sensitive to speed and landing gear pattern. Its history of reliability of engagement is not up to either of the other systems.

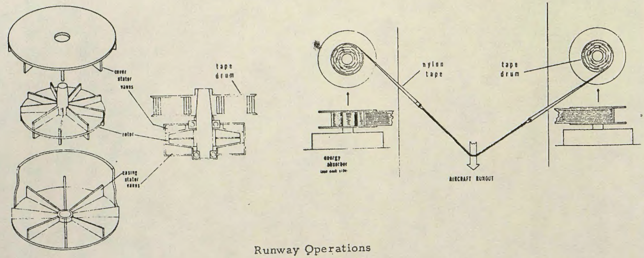
Limited study of various illustrations and conceptual drawings of the two Space Shuttle vehicles lead to a judgment that a net to accommodate both the Orbiter and the Booster would be a difficult design, particularly in view of the size of the Booster in some of the high winged, twin tailed versions. At best, it is felt that different nets would be required for the two vehicles.

Since the whole Space Shuttle system is under unilateral control, the ability to specify a tailhook exists. It is our recommendation that this approach should be taken if emergency overrun arrestment of these space vehicles is considered. The penalties are small; a 2G hook on the Boeing 720 added 0.1% to the empty weight of the aircraft as a retrofit. Designed into the structure from the outset, this level should be easily achievable. With hooks on both vehicles and a dual Model 64, single system engagements can be made by the Orbiter and for Booster landings, both pairs of energy absorbers can be coupled to a single cross runway cable. This method of doubling system capacity has been successfully tested by the U. S. Air Force and All American Engineering Company.

SUMMARY

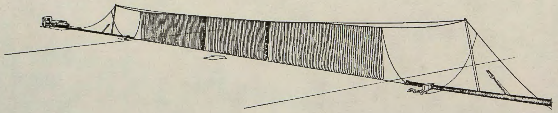
The potential for an overrun of one of the Space Shuttle vehicles exists. The art of arresting an aircraft on a runway is highly developed and equipment now exists which is capable of arresting either the Orbiter and the Booster portions of the Space Shuttle. Tailhook arrestment could be readily provided for and might well prevent the needless destruction of a very expensive space vehicle. An evaluation of the merits of overrun arrestment should be a part of the system planning effort.

Figure 1

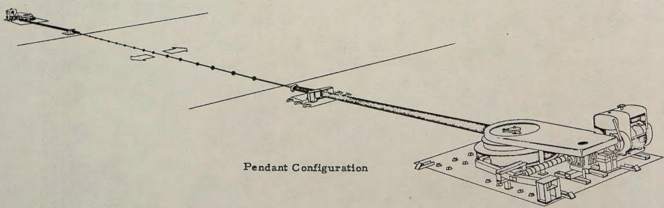


Runway Operations

Figure 2



Alternate Net Configuration



Pendant Configuration

GENERAL ARRANGEMENT
WATER TWISTER ARRESTING SYSTEM

Figure 3

TYPICAL COMPUTER PERFORMANCE

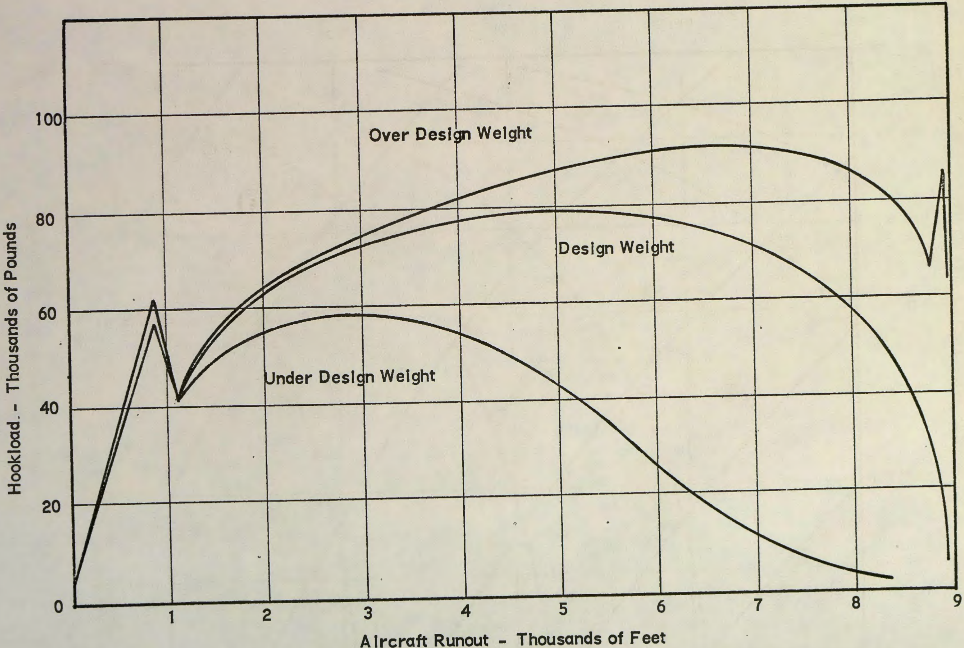


Figure 4

MODEL 64 PERFORMANCE

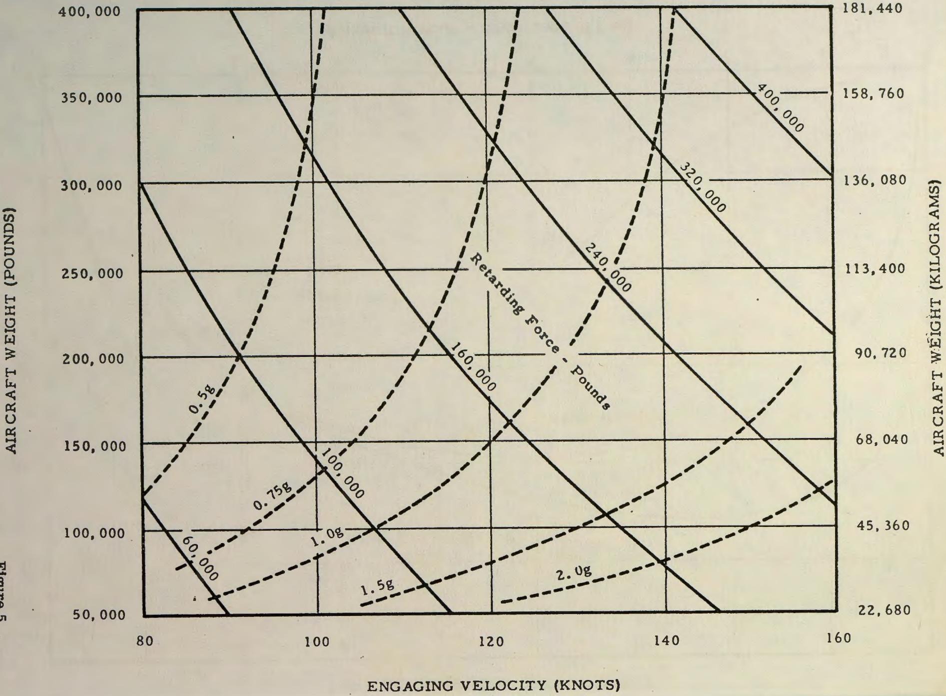


Figure 5